PAPER • **OPEN ACCESS**

Behavior of a welded-deposited stainless steel tested at different cavitation test conditions

To cite this article: H L Alwan *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **681** 012002

IOP Conf. Series: Materials Science and Engineering **681** (2019) 012002 doi:10.1088/1757-899X/681/1/012002

Behavior of a welded-deposited stainless steel tested at different cavitation test conditions

H L Alwan[1,2,a], Yu S Korobov[2,3,b], N N Soboleva[2,4,c], N V Lezhnin[3,d], A V Makarov[2,3,4,e], M S Deviatiarov [5,f], D M Elkind[2]

[1]University of Technology, Baghdad, Iraq;
[2]Ural Federal University named after the first President of Russia B.N. Yeltsin, Yekaterinburg, Russian Federation;
[3]M.N. Miheev Institute of Metal Physics, Ural Branch of the Russian Academy of Sciences, Yekaterinburg, Russian Federation;
[4]Institute of Engineering Science, Ural Branch of the Russian Academy of Sciences, Yekaterinburg, Russian Federation
[5]Ural Welding Institute-Metallurgy, Yekaterinburg, Russian Federation

E-mail: [a]lefta.hussam@gmail.com, [b]yukorobov@gmail.com, [c]natashasoboleva@list.ru [d]nlezhnin@bk.ru, [e]av-mak@yandex.ru, [f]dms@mashprom.ru.

Abstract. Two different ultrasonic vibratory-cavitation test conditions have been applied to a welded-deposited austenitic stainless steel AISI 321 to evaluate the resistance of deposited layer to cavitation erosion-corrosion. The cavitation test was conducted utilizing two test fluids; water and 3.5% NaCl solution. In addition, a certain voltage difference has been applied between the test specimen and water to form a combination effect. The welding wire of the AISI 321 stainless steel was deposited onto AISI 1040 steel substrate by using tungsten inert gas welding process. To evaluate and compare the behavior of the deposited material, the cumulative mass loss curves were attained and discussed. Moreover, the surface topography and scanning electron microscope (SEM) micrographs were utilized to characterize the worn surface after the cavitation tests. The results showed that the surface subjected to cavitation was more affected when applying water-voltage condition comparing with the 3.5% NaCl solution condition. The results of material loss, surface roughness and scanning electron microscope are fairly consistent with each other. This study highlights the effect of electrochemical-mechanical combinations on resistance to cavitation erosion-corrosion.

1. Introduction

Cavitation is a type of wear that deteriorates material surface for the components subjected to underwater erosion such as hydro turbines, valves, pumps impeller. When a solid component moves in high speed through a liquid, high and low pressure regions form due to the relative motion between the component and liquid. This leads to frequent formation and collapsing bubbles near the solid surface, and so, high pressure shock waves and micro-jets can produce and damage the surface. Maximum pressure was found to be at the end stage of bubble collapse. It can reach to1750 MPa and the velocity of liquid jet released ranges from 120 m/s to several of 100 m/s. Consequently, loss of material takes place and small pits or cavities appear over the surface, affecting the performance of components and reduction their lifetime [1-7].

It is known that the damaged surfaces of components due to cavitation can be restored by using the basic methods such as Metal Arc Welding (MAW) and Gas Tungsten Arc Welding (GTAW). Depositing the protective materials onto the origins to repair the defects or to combat cavitation erosion attack, can be achieved by those methods [8,9]. The behavior of material in the cavitation test differs by the test modes applied [10]. Various test liquids are usually used by the research works to evaluate the resistance to cavitation erosion such fresh water [11] and tap water [12]. The 3.5% NaCl solution is commonly used as a test liquid [11-14]. In addition, applying a voltage to the test forms a combined effect of mechanical and electrochemical interaction as well as accelerate forming the cavities [15]. In the present study, the water-voltage and 3.5%NaCl solution conditions were applied to evaluate the cavitation erosion–corrosion resistance of deposited AISI 321 stainless steel wire. Research works have been focused on wear resistance of this type of steel more than, in particular, on resistance to cavitation [16, 17]. Thus, in the present study, the deposited AISI 321 material was studied to evaluate its performance in resistance to cavitation erosion–corrosion.

2. Experimental Procedure

2.1 Tested materials and depositing technique. The solid welding wire of stainless steel AISI 321 (equivalent to steel 06KH19N9T or "06X19H9T" manufactured according to the Russian standard GOST 18143-72) was deposited onto AISI 1040 steel substrate. The gas tungsten arc welding or tungsten inert gas welding (GTAW or TIG) process was utilized to deposit the 1.6 mm diameter welding wire with current of 120 A and voltage of 10-12 V. Three layers of stainless steel wire have been deposited onto substrate, and the final deposition thickness about 4 mm. The chemical compositions of the deposited material and substrate are shown in Table 1.

Table 1. Chemical compositions of deposited material and substrate [wt. %]

Material	C	Cr	Ni	Si	Mn	Cu	P	S	Ti	Fe
AISI 321	Max. 0.08	18.0-20.0	8.0-10.0	0.40-1.00	1.00-2.00	-	Max. 0.03	Max. 0.015	Min. 5×C	Bal.
AISI 1040	0.404	-	-	0.283	0.6	0.142	0.0053	<0.001	-	Bal.

2.2 Specimens and cavitation test. The cavitation test specimens were prepared according to the requirements of performing the cavitation erosion test, which is the ASTM standard G32–10[18]. Using cylindrical substrate blocks with dimensions $\phi 24\times 20$ mm, the stainless steel wire was firstly deposited on them, and then, the substrate blocks were machined to the final required dimensions. All the machined specimens were ground together by silicon carbide grinding wheel to obtain the same surface state. The evaluation of surface resistance of the deposited material was conducted by obtaining the curves of cumulative weight loss for the two test conditions used in this study. Cavitation test was conducted under vibration frequency of 20 kHz, peak-to-peak amplitude of 50 μm, power of 500 W and applying voltage of 12 V. Fig. 1 shows the working principle of the cavitation test developed by authors [19], in which, the test specimen is attached to the vibratory horn. The specimens were exposed to 270 minutes of test. The procedure of conducting cavitation experiments included cleaning the test specimen by acetone, drying by hot air for 30-40 seconds, and weighing the specimen using a weight device with an error of 0.5 mg.

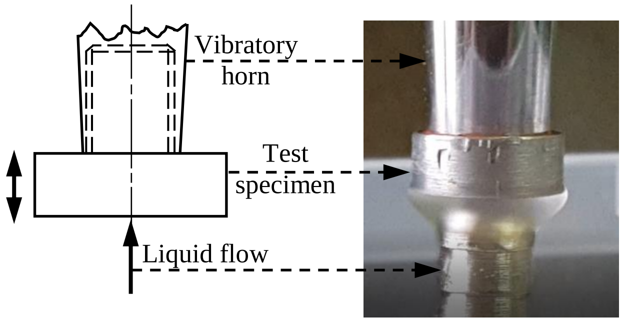

Figure 1. Work principle of the cavitation test facility.

2.3 Equipment. The necessary equipments that have been used for evaluating the eroded surface, in addition to the cavitation vibratory device, included the optical profilometer Wyko NT 1100 and scanning electron microscope (SEM) TescanVEGA II XMU. Surface roughness was measured several times over the intended surface to determine the value of the arithmetic mean deviation of the roughness profile Ra. In addition, Shimadzu HMV-G21DT microhardness tester was used for measuring the microhardness of the surface exposed to cavitation under a load of 0.49 N as an arithmetic mean of 10 measurements.

3. Results and Discussion

3.1 Cavitation curves. The ultrasonic vibratory method was used to induce forming cavities over the tested surface of the deposited material. The relationship between the exposure time and the mass loss was plotted for a number of periods. This relationship is one of indications to surface resistance to cavitation erosion. Fig. 2 shows the results of mass loss for the two test conditions. Although the material loss produced by the water-voltage condition is more than that of 3.5% NaCl solution, the difference in material loss is not significant during the cavitation test. The same conditions (water-voltage and 3.5% NaCl solution) were applied on AISI 1040 in a previous study [10], and there was a significant difference in material loss, which was estimated approximately 4 times at the last of the test. However, the material loss of AISI 321 was about 8.3 mg when applying the water-voltage condition, while it was about 6.2 mg using 3.5% NaCl solution condition. It was compared with the substrate AISI 1040 which has been tested at similar cavitation test parameters in the previous research work [20], where the cumulative material loss of AISI 1040 was about 125 mg. Fig. 3 shows the cumulative mass loss curves for the AISI 1040 and the AISI 321 steels.

3.2 Surface roughness and microhardness. Surface roughness is an important factor in resistance to cavitation, and it can be considered as a useful indicator in evaluating the eroded surface. Table 2 represents the arithmetic mean deviation of the roughness profile Ra for five measures taken on the surface of the AISI 321 stainless steel at the same area of measurement. Regarding the microhardness, the $HV_{0.05}$ had been measured for the surface to be exposed to cavitation effect and was found to be 420 ± 40. The good mechanical properties of stainless steel have certainly positive effects in resistance to cavitation erosion. Many research works have shown that the mechanical properties, e.g. hardness, affect the resistance to cavitation in stainless steels. It has been reported that the hardness is inversely proportional to cavitation erosion [21, 22].

Table 2. The arithmetic mean deviation of the roughness profile Ra for the deposited AISI 321 stainless steel before and after applying the two cavitation test conditions.

Condition	Value of Ra [μm]
Before cavitation test	0.71
Water-Voltage condition	1.06
3.5% NaCl solution condition	0.91

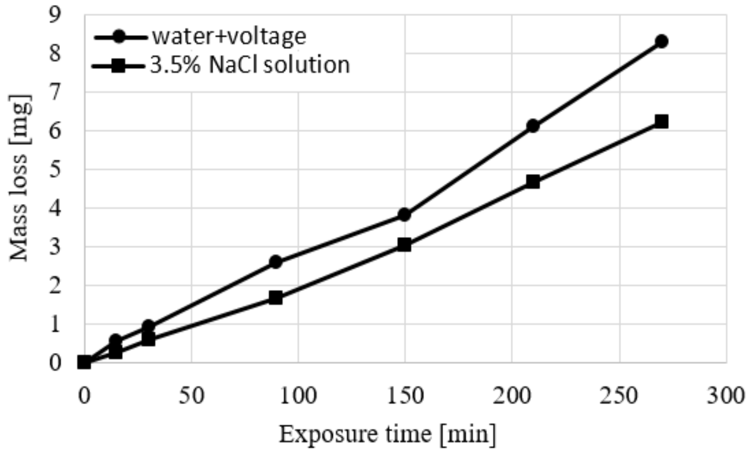

Figure 2. Results of cavitation vibratory test ("mass loss – time" curve) for the AISI 321.

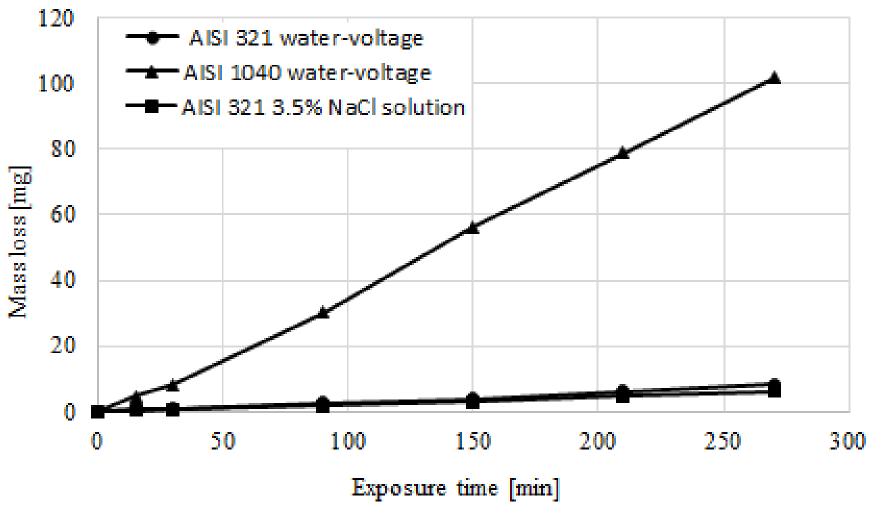

Figure 3. Cumulative mass loss-time curve for the deposited AISI 321 stainless steel and AISI 1040 substrate.

3.3 Topographical and SEM images. Surface topographical images and scanning electron microscope (SEM) micrographs have been utilized to evaluate the eroded surfaces of the welded-deposit stainless steel AISI 321. Fig. 4 shows the SEM micrographs of the eroded surfaces at different magnification for the two cavitation test conditions. It can be noticed that the surface exposed to water-voltage condition is more affected by cavitation, as shown in Figs. a, b, and c, than of that subjected to the 3.5% NaCl solution as shown in Figs. d, e, and f. Comparing the size and appearance of cavities in the eroded surface, they appear to some degree to be big in size, deep, and dense as shown in Fig. 4c. This is due to the effect of voltage applied which forms a combination action, although the second cavitation test condition (3.5% NaCl solution) is not considered as a pure cavitation erosion.

Regarding the surface roughness and texture of the deposited material, Fig. 5 shows three-dimensional topographical images of the original surface before testing and the eroded surfaces when applying the two cavitation test conditions. The same indication can be considered when evaluating the topographical images of the eroded surfaces and the values of surface roughness Ra. The average values of the arithmetic mean deviation of the roughness profile Ra resulted from five measures taken for the same area of measure, were found to be as represented in Table 2. The maximum value of Ra was as a result of applying water-voltage condition, which was of 1.06 μm, while it was of 0.91 for the 3.5% NaCl solution condition. This gives an indication that the damage caused by water-voltage condition is more than of that caused by the 3.5% NaCl solution. As for the texture of the original and eroded surfaces shown in Fig. 5, it can be clearly seen the surface topography for each one. The grinding lines appear on the original surface to be tested as shown in Fig. 5a, and this surface is the initial state for comparison. The eroded surface shown in Fig. 5a represents the surface exposed to water-voltage cavitation test condition, and it appears to be more affected comparing with the others. Fig. 5c is the eroded surface when applying the 3.5% NaCl solution condition, and it seems to be less damaged than of that shown in Fig. 5b. It can be noticed the grinding line along the center of the surface shown in Fig. 5c. It can be evidence to ensure that the surface is less affected by the cavitation. These results are consistent with the results of cavitation tests, surface roughness values Ra, and the SEM micrographs of the eroded surfaces.

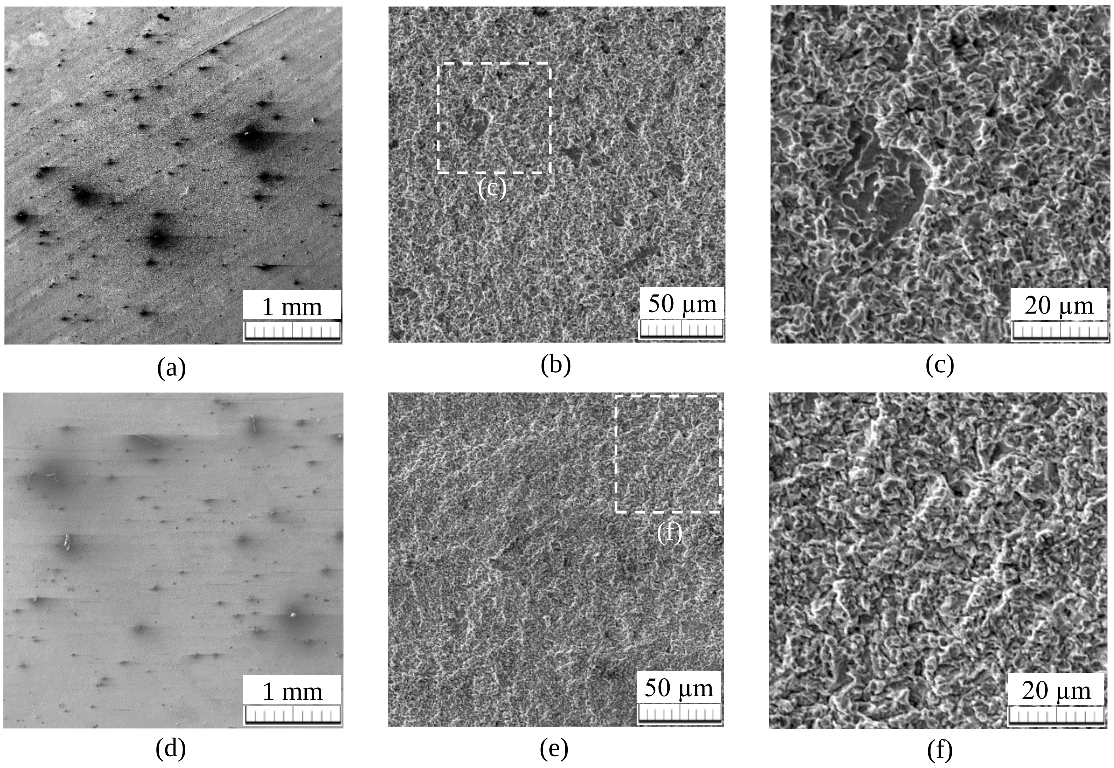

Figure 4. SEM micrographs of the eroded surfaces of AISI 321 for the two cavitation test conditions: a, b, c – water-voltage condition; d, e, f – 3.5% NaCl solution condition.

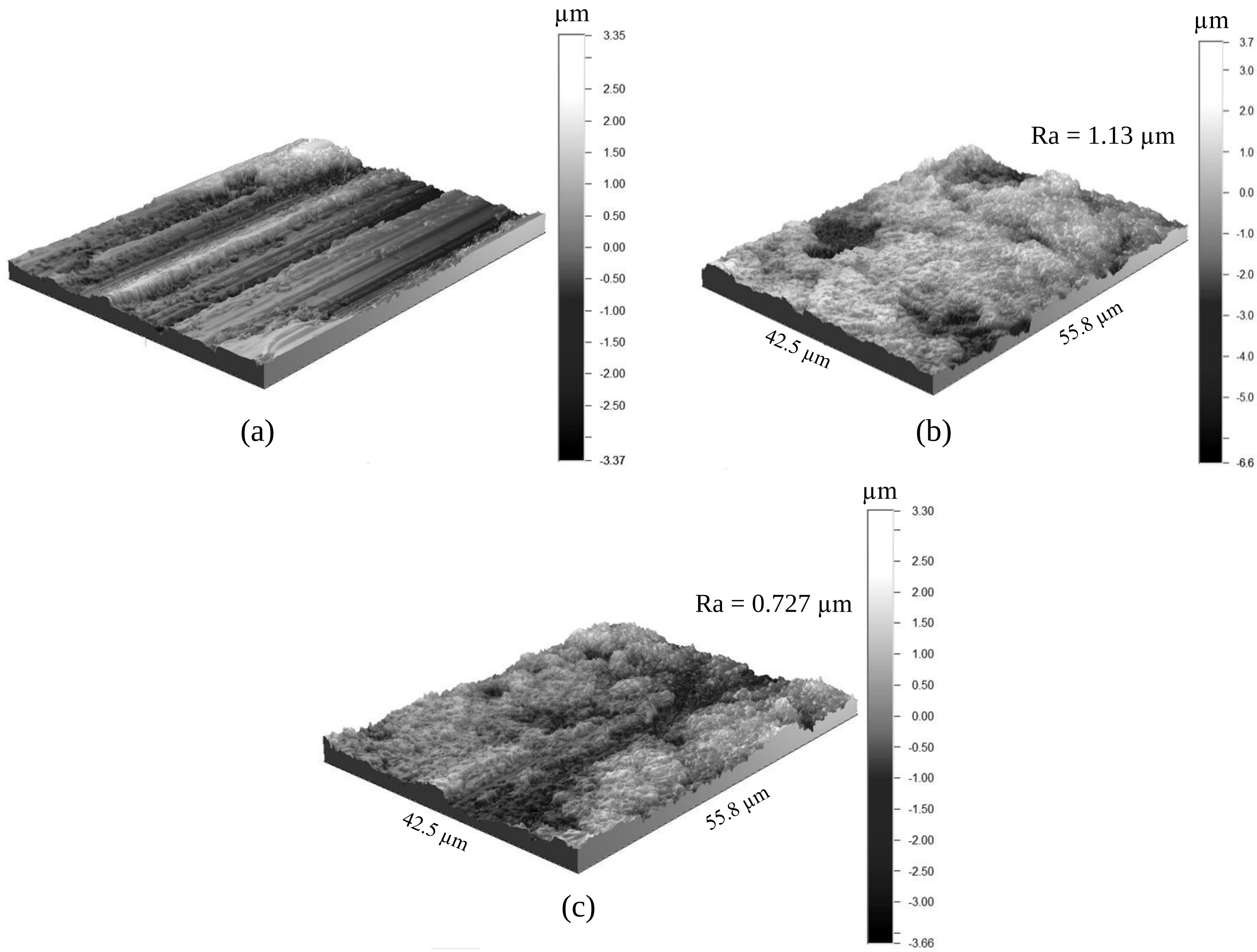

Figure 5. Surface topography and Ra values of the AISI 321 before and after testing: a – original surface before cavitation test, b – water-voltage condition, c – 3.5% NaCl solution condition.

4. Conclusion

The welding wire of AISI 321 stainless steel was deposited by using gas tungsten arc welding process onto the AISI 1040 substrate. The ultrasonic vibratory tests, surface topography and scanning electron microscope - SEM micrographs were used to evaluate the cavitation erosion-corrosion resistance of the deposited layer. The main results are as follows:

- The deposited layer was more damaged when applying the water-voltage condition comparing with applying the 3.5% NaCl solution condition. This is due to the significant effect of voltage which induces an electrochemical action.
- Ultrasonics vibratory cavitation tests showed that the mass loss for the water-voltage condition was higher comparing with using the 3.5% NaCl solution.
- The results of surface topography and scanning electron microscope micrographs are consistent with cavitation tests in terms of the eroded surfaces and the values of Ra.
- Cavitation erosion-corrosion resistance of deposited AISI 321stainless steel layer is 12 times as high comparing with the 1040 steel substrate.

Acknowledgement

This work was done within the state order of IMP UB RAS on the subject no. AAAA-A18-118020190116-6, within the state order of IMP UB RAS on the subject “Laser”, and IES UB RAS on the subject no. AAAA-A18-118020790147-4. The present study was supported by FASIE, program Development-NTI 2017, project No. 0035960. Microhardness, surface roughness and SEM were done on the equipment installed at the Plastometriya collective use center of IES UB RAS.

References

[1] G.W. Stachowiak and A.W. Batchelor, Engineering Tribology, Butterworth-Heinemann, 2013.
[2] J-P Franc, M. Riondet, A. Karimi, G. L. Chahine, Material and velocity effects on cavitation erosion pitting, Wear 274– 275 (2012) 248– 259.
[3] L.A. Espitia and A. Toro, Cavitation resistance, microstructure and surface topography materials used for hydraulic components, Tribology International 43 (2010) 2037–2045.
[4] J.F. Santa, J.A. Blanco, J.E. Giraldo, A. Toro, Cavitation erosion of martensitic and austenitic stainless steel welded coatings, Wear 271 (2011) 1445–1453.
[5] E.A. Brujan, T. Ikedab, Y. Matsumoto, Shock wave emission from a cloud of bubbles, Soft Matter 8 (2012) 5777–5783.
[6] W. Lauterborn and H. Bolle, Experimental investigation of cavitation bubble collapse in the neighborhood of a solid boundary, J. Fluid Mech. 72 (1975) 391–399.
[7] M. Dular, B. Bachert, B. Stoffel, B. Širok, Relationship between cavitation structures and cavitation damage, Wear 257 (2004) 1176–1184.
[8] K. Nakata, M. Oishi, M. Koshiishi, T. Hashimoto, H. Anzai, Y. Saito, W. Kono, Re-weldability of neutron-irradiated stainless steels studied by multi-pass TIG welding, J. Nucl. Mater. 307 (2002) 1578–1583.
[9] A. Shah, M. Rayjada, S. Gupta, Investigating mechanical properties of SAW and SMAW welded joints & the effect of SMAW-repair of saw welded specimen, IJMPE 3 (2015) 66–70.
[10] H.L. Alwan, N. Lezhnin, Yu. Korobov, Analysis of the external conditions affecting on the cavitation resistance of a steel, Trans Tech Publications, Switzerland 946 (2019) 31–36.
[11] S. Han, J.H. Lin, J.J. Kuo, J.L. He, H.C. Shih, The cavitation-erosion phenomenon of chromium nitride coatings deposited using cathodic arc plasma deposition on steel, Surf. Coatings Technol., 161 (2002) 20–25.
[12] S.A. Karrab, M.A. Doheim, M.S. Aboraia, S.M. Ahmed, Examination of Cavitation Erosion Particles Morphology in Corrosive Waters, J. Eng. Sci. Assiut Univ. 40 (2012) 1793–1814.
[13] C.T. Kwok, H.C. Man, F.T. Cheng, Cavitation erosion of duplex and super duplex stainless steels, Scr. Mater. 39 (1998) 1229–1236.
[14] Y.X. Qiao, X. Cai, C. Ouyang, Y.G. Zheng, Effect of Hydrogen on Cavitation Erosion Behaviour of High Strength Steel, Int. J. Electrochem. Sci. 11 (2016) 10329–10346.
[15] Y. Zheng, S. Luo, W. Ke, Effect of passivity on electrochemical corrosion behavior of alloys during cavitation in aqueous solutions, Wear 262 (2007) 1308–1314.
[16] A.N. Grigorchik, V.A. Kukareko, M.A. Belotserkovskii, A.V. Belyib, Structure and wear of sprayed 06X19H9T steel coatingsafter ion-beam nitriding, Steel in Translation 44 (2014) 126–29.
[17] A.V. Byeli, M.A. Belotserkovskii, V.A. Kukareko, Microstructure and wear resistance of thermal sprayed steel coatings ion beam implanted with nitrogen, Wear 267 (2009) 1757–1761.
[18] ASTM, Standard Test Method for Cavitation Erosion Using Vibratory Apparatus, G 32 - 10, (2011) 1–19.
[19] Yu.S Korobov, H.L. Alwan, M. Barbosa, N.V. Lezhnin, N.N. Soboleva, A.V. Makarov, M.S. Deviatiarov, A.Yu. Davydov, Cavitation erosion-corrosion resistance of WC–CoCr and WC–NiCr HVAF coatings, Bulletin PNRPU. Mechanical engineering, materials science 21 (2019) 20–27.
[20] H.L. Alwan, Yu.S. Korobov, N.N. Soboleva, N.V. Lezhnin, A.V. Makarov, E.P. Nikolaeva, M.S. Deviatiarov, Cavitation erosion-corrosion resistance of deposited austenitic stainless

steel/E308L-17 electrode, International conference on Industrial Engineering, Sochi, Russian Federation 25-29 March 2019 Journal Solid State Phenomena, in press.
[21] A. Selokar, U. Prakash, D.B. Goel, B.V.M. Kumar, Cavitation erosion and solid particle erosion behaviour of a nitrogen alloyed austenitic stainless steel, ISIJ International 55 (2015) 1123–1130.
[22] A.W. Selokar, D.B. Goel, U. Prakash, A comparative study of cavitation erosive behaviour of 23/8N nitronic steel and 13/4 martensitic stainless steel, Advanced Materials Research 585 (2012) 554–558.